Circular No. 595

February 1941 • Washington, D. C.

UNITED STATES DEPARTMENT OF AGRICULTURE

The Growth and Composition of the Fruit of Okra in Relation to its Eating Quality

By C. W. Culpepper, *physiologist*, and H. H. Moon, *assistant pomologist, Division of Fruit and Vegetable Crops and Diseases, Bureau of Plant Industry*

CONTENTS

INTRODUCTION

The okra plant (*Hibiscus esculentus* L.) is widely grown for its fruit which, in the immature state, has been used as a food for at least eight centuries (*8*).[1] Because of the nature of its use, it is ordinarily classed as a vegetable. The characteristics of the plant and its cultural requirements have been stated by Beattie (*2*) and by Jones and Rosa (*9*). Its uses in cookery are discussed by several writers (*2, 7, 10*). Methods of canning it have been described by Cruess (*5*) and others (*3, 10, 11*). From time to time it has been analyzed for various constituents, and these analyses have been summarized by Chatfield and Adams (*4*). Woodroof (*14*) discusses some practical problems in the production and use of the material. He reports (*14, p. 180*) the analytical results of Friedeman giving the composition of several varieties of the edible immature fruits and of the mature inedible material. Winton and Winton (*13*) have summarized the results of various studies of the morphology and anatomy of the plant and of the chemistry of the fruit. No one seems to have followed closely the changes in composition with growth and development of the fruit.

[1] Italic numbers in parentheses refer to Literature Cited, p. 17.

264647°—41——1

PURPOSE OF THE STUDY

The present investigation was carried out for the purpose of determining the nature of certain chemical changes in the fruit of the okra plant as growth and ripening occur, and of correlating these, insofar as possible, with the rate of growth and the eating quality of the material. It also seemed of interest to ascertain the effect of temperature upon the rate of growth at various stages during the growing period.

In addition to the study of the growth and changes in chemical composition of the fruit as a whole, similar studies were made separately upon the ovarial wall, the placental tissue, and on the seeds, separate sets of samples of each being preserved for the purpose.

The changes in the eating quality of the fruit accompanying the changes in composition were determined by means of cooking and canning tests.

MATERIALS AND METHODS

The material for the chemical analyses was grown at the Arlington Experiment Farm, Arlington, Va., on a fertile, sandy soil formed by dredging operations along the Potomac River. The Perkins Improved variety was used. The planting was made June 2, and the plants began fruiting in August. For the purpose of identifying fruits of known age, a record was kept of the flowering dates for a large number of fruits by labeling each fruit with a tag bearing the date on which the flower expanded. Fruits were harvested as they reached the stage of maturity generally considered desirable for cooking. The samples were taken between August 23 and September 20. The temperature was intermediate between those of the hottest part of the summer and those of the cooler fall and averaged 67° F., but the first 10 days of the period averaged about 70°, whereas the last 10 averaged 64°. Under these conditions it would be expected that the development in the early days of the period would be somewhat more rapid than that of the latter part.

Methods of Analyzing the Material

Samples were taken on the day the flowers opened and at 1- to 4-day intervals until the fruits were 34 days old. The fruits of the oldest samples were beginning to dry slightly at the tip, and the majority of the seeds were black and fully developed but not dry. The samples were collected about 10 a. m., weighed, and the length and diameter of each fruit recorded. Fifty to one-hundred fruits were required to give sufficient material for the chemical samples in the first three or four stages. For the older material 10 to 12 fruits were taken at each sampling. After chopping the material into small pieces and mixing, 100-gm. samples were weighed out in triplicate and 95-percent alcohol was added to make the final concentration 75 to 80 percent. The alcohol was brought to a boil, and the tops of the jars in which the samples were preserved were clamped down while the alcohol was boiling. which excluded most of the air from the containers.

Two series of samples were taken, one of the entire fruits taken at intervals beginning at date of bloom and continuing to the 34-day stage of maturity, the other in which the fruits were separated into

seeds, wall, and placental regions. Samples for the latter series were taken at 4-day intervals from the 10-day stage to the 34-day stage. The weights of the different parts of the fruit were obtained and the proportional amounts of each calculated as percentages of the whole fruit.

The samples were extracted by decanting the alcohol through an extraction thimble, the residue was then ground, placed in the extraction thimble, washed repeatedly with small quantities of alcohol, and the washings added to the alcohol used for preservation of the sample. The thimble containing the material was then placed in a Soxhlet apparatus and extracted 8 hours with 95-percent alcohol.

The extracts were combined, made up to volume and aliquot portions used for the determination of soluble solids, sugars, acids, and total astringency. The residue was dried and weighed, giving the value for the insoluble solids.

The soluble solids were determined by taking triplicate 25-cc. aliquots of the extract, evaporating off the alcohol at 60° C. on a water bath, then drying the solids over calcium oxide in a vacuum oven under an absolute pressure of 5 inches of mercury at a temperature of 75° C. The weight of the soluble and the insoluble solids, combined, gave the total weight of solids of the sample.

Sugars were determined by the volumetric permanganate modification of the Munson-Walker method, total astringency by the modified Loewenthal-Procter method, total acidity by titration with N/10 sodium hydroxide and calculated as citric acid, and total nitrogen by the Gunning-Arnold method, all as described in the official methods of the Association of Official Agricultural Chemists (*1*).

Methods of Study of the Growth

From the records of the average fresh weight per fruit and the percentage composition, the net accumulation of the various constituents in the fruit for each interval of the period of sampling has been calculated. This gives a record of the growth and quantitative chemical change that occurred during the period in which the samples were taken. It did not appear feasible to make a sufficient number of determinations upon material grown at different temperatures to ascertain the relation of temperature to the rate of change of the various chemical constitutents. The influence of temperature upon the rate of growth of the fruit appeared to be of sufficient importance, however, to warrant an effort to obtain some information as to its effect. Consequently, the effect of the prevailing temperature upon the rate of increase in length of the fruit as grown under field conditions was determined. Measurements were made of the length of several hundred growing fruits at 24-hour intervals from the time the bloom was shed until growth ceased. These data were accumulated by making a series of measurements of growing fruits at various periods throughout the season from July to killing frost, and continuing such series of measurements during three successive growing seasons. In each series there were included fruits of all ages, from those which had just dropped the petals to those which had practically completed their growth. Consequently, each series of measurements afforded material for study of the effect of the prevailing temperature upon fruits at various stages of development.

Records of the prevailing air temperatures were made by means of a carefully calibrated thermograph placed in the field in the midst of the growing plants. The measurements of growth were made by means of calipers graduated in millimeters. The measurements were made at 24-hour intervals and were always taken in the early morning, when the fruits were fully turgid. The growth rate is thus based upon a 24-hour period. The mean hourly temperature for each period was taken as the prevailing temperature. Many measurements were made twice each day at about 9 to 10 a. m. and at 4 to 5 p. m., but these were used only to determine the effect of day and night upon the rate of growth.

The measurements upon the fruits were made at all lengths beginning at date of bloom and continuing until they reached full length. Thus the effect of temperature upon the changes in size and composition of the fruits at various stages of growth was determined.

The difference in the length of the fruit at the beginning and at the end of each period was taken as the growth increment of the period. The length of the fruit for the period was taken as the average of its length at the beginning and at the end of the period.

The data as tabulated included several thousand measurements made at various temperatures and at all stages of growth. The measurement readings were then classified into 8 groups according to the temperature prevailing during the period in which they were taken. Those between 45° and 50° F., averaging 47.5°, constituted the first group; those between 50° and 55°, averaging 52.5°, the second; and so on at 5° intervals, the last interval being 80° to 85°, averaging 82.5°. The data in each group were then classified into 6 subgroups according to the length of the growing fruit. Readings on fruits 1 to 3 cm. long were put into 1 subgroup, those 3.1 to 6 cm. long into a second subgroup, and so on at 3 cm. intervals to 15 cm. All fruits between 15 and 20 cm. were put into the last group. Thus 48 classes were made. The values in each class were then averaged and the results tabulated. The method of classification will be apparent from table 1. The means thus obtained were then plotted, first with temperature as the abscissa, giving a system of 8 curves, and then with fruit length as the abscissa, giving a system of 6 curves. By means of a spline, curves were fitted to the points plotted in such a way as to make the sum of the squares of the deviations as nearly a minimum as could be determined by simple arithmetical calculations. The values of the growth rates represented by the midpoints of each of the class intervals were read from the smoothed curves for both systems of curves.

TABLE 1.—*Effect of temperature and stage of development upon the rate of growth of the fruit of the okra plant under field conditions*

Length of fruit (centimeters)	Rate of growth per 24 hours at mean temperatures (°F.) shown							
	47.5°	52.5°	57.5°	62.5°	67.5°	72.5°	77.5°	82.5°
	Centimeter	*Centimeter*	*Centimeter*	*Centimeters*	*Centimeters*	*Centimeters*	*Centimeters*	*Centimeters*
0–3.0	0.21	0.25	0.30	0.38	0.50	0.68	0.90	1.15
3.1–6.0	.29	.38	.50	.71	1.01	1.33	1.71	2.12
6.1–9.0	.38	.55	.77	1.09	1.49	1.94	2.45	2.96
9.1–12.0	.42	.66	.96	1.35	1.77	2.24	2.78	3.36
12.1–15.0	.43	.67	.97	1.36	1.77	2.23	2.77	3.34
15.1–20.0	.32	.43	.58	.80	1.10	1.50	1.97	2.50

Corresponding values in the two systems of curves obviously should be the same, but there were a number of small discrepancies. Corresponding values of the growth rates in the two systems of curves were then averaged and the results again plotted in the same way as at first. Values of the growth rates at corresponding points in the two systems of curves now agreed much more closely than was the case at first. The process was repeated two additional times, thus obtaining values that lay almost exactly upon smooth curves, no matter in which way they were plotted. The final results represented the most probable values of the growth rates for the entire set of observations.

Methods of Making Cooking and Canning Tests

Each cooking test was made by taking 10 to 12 fruits of known age, washing, removing the inedible stems and basal portions, placing the fruits in a convenient-size kettle to which was added sufficient 2-percent brine to cover them, bringing the solution to a boil, and boiling for 20 minutes. The degree and character of the flavor was estimated by tasting and the presence of fiber and other characteristics determining the texture were noted. The different samples were also compared with respect to color and general appearance. The tests were all made on the same day with fruits from 4 to 14 days of age and differing in age by 2 days.

Sufficient numbers of fruits that had been tagged at blooming were not available for the canning tests, hence, the ages of the fruits used were estimated from their length as compared with the length of a representative number of tagged fruits. Tests were made at 6, 8, 10, and 12 days of age. After washing and removing the inedible basal portion, the fruits were chopped into pieces ¾ to 1 inch in length. These were placed in No. 2 enameled tin cans and 2-percent brine was added, leaving the proper head space. The cans were exhausted 4 minutes, sealed, then processed at 15 pounds steam pressure for 40 minutes, and cooled in water. After approximately 5 months in storage the cans were opened and the color, texture, and flavor of the contents noted, as in the case of the cooked material.

EXPERIMENTAL RESULTS

Composition of the Entire Fruit

Results of the chemical analyses of the entire fruit are given in table 2. From the standpoint of the use of the fruit as a food it is low in nutritive value, because it is low in its content of soluble solids, sugars, and acidity and only medium in the amount of total solids, total nitrogen, and astringency present. Certain constituents vary considerably with the age of the fruit whereas others change very little. The effect of age on the composition is shown by the curves in figure 1.

Under the conditions prevailing during the growth of the material used in these tests, the percentage of total solids present in the fruit decreased from date of bloom to about the 14-day stage, after which it increased to the 34-day stage. The soluble solids did not change very greatly with increase in age. Consequently, the changes in the insoluble solids very closely parallel the changes in the total solids.

TABLE 2.—*Changes in composition of the fruit of the okra plant and the accumulation of some chemical constituents with increase in age*

Plant part	Date sampled	Age	Fresh weight per fruit	Soluble solids	Total soluble solids per fruit	Insoluble solids	Total insoluble solids per fruit	Total solids	Total solids per fruit	Reducing sugar	Total reducing sugar per fruit	Nonreducing sugar	Total nonreducing sugar per fruit	Total sugar	Total sugar per fruit	Titratable acidity	Total titratable acidity per fruit	Total astringency	Total astringency per fruit	Total nitrogen	Total nitrogen per fruit
		Days	*Grams*	*Per cent*	*Grams*	*Per cent*	*Grams*	*Per cent*	*Grams*	*Per cent*	*Gram*	*Per cent*	*Gram*	*Per cent*	*Grams*	*Per cent*	*Gram*	*Per cent*	*Gram*	*Per cent*	*Gram*
	Aug. 23	0	0.49	4.87	0.024	13.17	0.065	18.04	0.089	0.57	0.003	1.41	0.007	1.98	0.010	0.199	0.0010	0.187	0.0009	0.866	0.0040
	Aug. 30	2	.62	4.37	.027	11.79	.073	16.16	.100	.60	.004	1.35	.008	1.95	.012	.239	.0014	.188	.0012	.789	.0049
	Sept. 4	4	1.63	4.10	.067	10.32	.168	14.42	.235	.51	.008	1.05	.017	1.56	.025	.185	.0030	.188	.0031	.631	.0103
	Sept. 1	6	4.52	5.05	.228	8.74	.395	13.79	.623	1.20	.054	1.38	.062	2.58	.116	.168	.0076	.103	.0047	.558	.0252
	Aug. 31	7	8.73	4.36	.381	8.05	.703	12.41	1.084	1.56	.136	.96	.084	2.52	.220	.207	.0181	.101	.0088	.507	.0443
	do.	10	22.41	4.66	1.044	6.24	1.398	10.90	2.442	2.06	.462	1.04	.233	3.10	.695	.230	.0515	.109	.0244	.409	.0917
Entire fruit	Sept. 11	12	35.02	4.52	1.583	5.63	1.972	10.15	3.555	1.85	.648	.84	.294	2.69	.942	.273	.0956	.118	.0413	.401	.1404
	Aug. 31	14	46.20	4.70	2.171	4.94	2.282	9.64	4.453	2.01	.929	.88	.407	2.89	1.336	.280	.1294	.111	.0513	.348	.1608
	Sept. 4	18	58.33	3.91	2.281	8.20	4.783	12.11	7.064	1.15	.671	.65	.379	1.80	1.050	.359	.2094	.109	.0636	.430	.2508
	Sept. 12	22	66.60	4.44	2.957	8.46	5.634	12.90	8.591	.92	.613	.69	.460	1.61	1.073	.307	.2041	.105	.0699	.495	.3297
	do.	26	64.81	4.07	2.638	12.83	8.315	16.90	10.953	.54	.350	.57	.369	1.11	.719	.271	.1756	.127	.0823	.597	.3869
	Sept. 20	30	63.62	4.12	2.621	15.95	10.148	20.07	12.769	.43	.274	.47	.299	.90	.573	.302	.1921	.126	.0802	.618	.3932
	do.	34	59.11	3.27	1.933	18.57	10.977	21.84	12.910	.32	.189	.44	.260	.76	.449	.288	.1702	.143	.0845	.669	.3954
	Sept. 1	10	4.07	5.31	.216	6.82	.278	12.13	.494	1.65	.067	1.35	.055	3.00	.122	.350	.0142	.204	.0083	.572	.0233
	Aug. 31	14	8.59	5.48	.471	7.08	.608	12.56	1.079	1.80	.155	1.77	.152	3.57	.307	.301	.0259	.233	.0200	.580	.0498
	Sept. 4	18	11.74	4.69	.551	10.86	1.275	15.55	1.826	.97	.114	1.28	.150	2.25	.264	.290	.0340	.190	.0223	.655	.0769
Seeds	Sept. 22	22	13.29	4.82	.641	14.62	1.943	19.44	2.584	.63	.084	1.67	.222	2.30	.306	.257	.0342	.188	.0250	.853	.1134
	Sept. 12	26	13.43	4.20	.564	20.52	2.756	24.72	3.320	.44	.059	1.00	.134	1.44	.193	.228	.0306	.164	.0220	1.148	.1542
	Sept. 20	30	13.28	4.17	.554	26.50	3.519	30.67	4.073	.53	.070	.67	.089	1.20	.159	.211	.0280	.140	.0186	1.387	.1842
	do.	34	12.81	4.24	.543	32.09	4.111	36.33	4.654	.33	.042	.60	.077	.93	.119	.166	.0213	.137	.0175	1.468	.1881
	Sept. 1	10	4.26	4.64	.198	4.91	.209	9.55	.407	2.10	.089	.66	.028	2.76	.117	.206	.0088	.114	.0049	.444	.0189
	Aug. 31	14	8.82	4.33	.382	4.45	.392	8.78	.774	1.41	.124	.94	.083	2.35	.207	.225	.0198	.115	.0101	.392	.0346
	Sept. 4	18	11.54	4.18	.482	7.93	.915	12.11	1.397	1.03	.119	.69	.080	1.72	.199	.310	.0358	.146	.0168	.507	.0585
Placental tissue	Sept. 22	22	13.59	3.41	.463	8.87	1.205	12.28	1.668	.60	.082	.62	.084	1.22	.166	.257	.0349	.123	.0167	.497	.0675
	Sept. 12	26	13.94	3.90	.544	8.84	1.232	12.74	1.776	.37	.052	.38	.053	.75	.105	.403	.0562	.160	.0223	.516	.0719
	Sept. 20	30	13.48	3.70	.499	12.05	1.624	15.75	2.123	.45	.061	.45	.061	.90	.122	.331	.0446	.180	.0243	.544	.0733
	do.	34	13.02	3.41	.443	12.63	1.644	16.04	2.087	.29	.038	.41	.053	.70	.091	.267	.0348	.197	.0256	.496	.0646
	Sept. 1	10	14.08	4.59	.646	5.48	.772	10.07	1.418	2.37	.334	.74	.104	3.11	.438	.200	.0282	.101	.0142	.366	.0515
	Aug. 31	14	28.80	4.23	1.218	5.91	1.702	10.14	2.920	1.81	.521	.54	.156	2.35	.677	.264	.0760	.090	.0259	.405	.1166
	Sept. 4	18	35.05	3.98	1.395	7.93	2.779	11.91	4.174	1.11	.389	.33	.116	1.44	.505	.254	.0890	.093	.0326	.422	.1479
Wall tissue	Sept. 22	22	39.92	4.02	1.597	9.31	3.698	13.33	5.295	1.16	.461	.62	.246	1.78	.707	.285	.1132	.089	.0354	.449	.1783
	Sept. 12	26	37.44	3.97	1.486	8.72	3.265	12.69	4.751	.38	.142	.38	.142	.76	.284	.363	.1359	.090	.0337	.419	.1569
	Sept. 20	30	36.86	4.03	1.485	13.31	4.906	17.34	6.391	.41	.151	.60	.221	1.01	.372	.297	.1095	.110	.0405	.484	.1784
	do.	34	33.28	3.50	1.165	15.66	5.211	19.16	6.376	.31	.103	.40	.133	.71	.236	.299	.0995	.117	.0389	.467	.1554

The total sugar content increased to about the 10-day stage and then decreased to the 34-day stage, although the results are somewhat irregular. The results show a tendency for the nonreducing sugar to decrease throughout the sampling period, although the differences are not very significant for the first 10 days. The reducing sugar very definitely increased to the 10-day stage, after which it declined to the 34-day stage.

The changes in the acidity and the astringent materials appear to be of little importance from the standpoint of the use of the material in cookery. The acidity increased slightly to the 18-day stage and

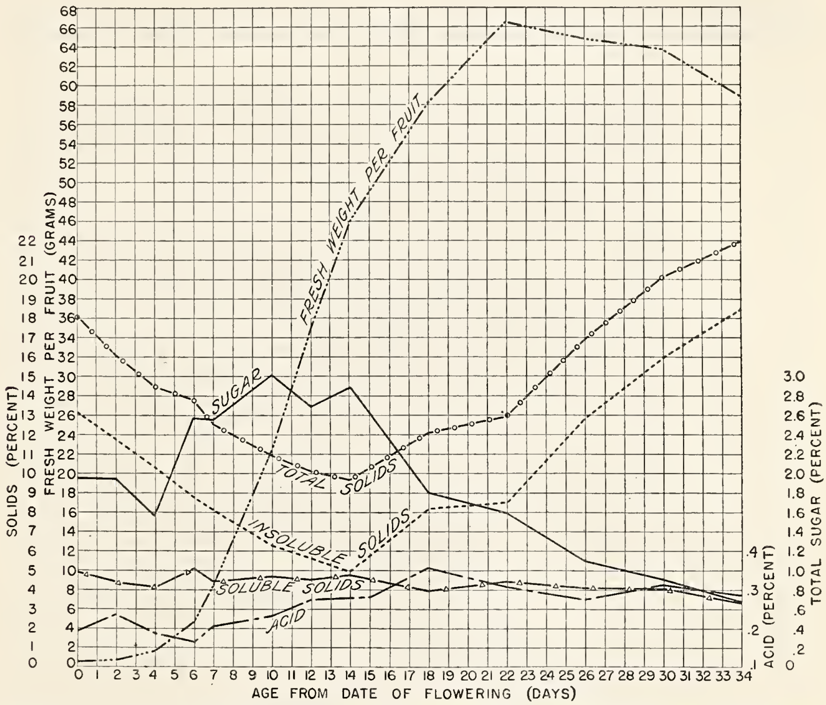

Figure 1.—Fresh weight and solids of the fruit of the okra plant when harvested at 2-day intervals from date of flowering.

then decreased to the 34-day stage. The astringency was highest in the samples of the first or bloom stage, lowest in the intermediate stages, but somewhat higher in the material of the last three stages.

Composition of Different Parts of the Fruit

The wall and placental regions are lower in their total solids content than the seeds, which with very few exceptions have a higher content of all the constituents of the total solids at all stages of maturity than the wall or placental tissues. There are generally no great differences between the wall and the placental tissues. The content of total solids, insoluble solids, reducing and total sugar tends to be slightly higher in the wall than in the placental region.

In the seeds the content of soluble solids, sugars, and titratable acidity decreased with age, whereas the insoluble solids, the total solids, and the total nitrogen increased with age. In the wall and placental tissues there was no marked change in the content of acidity and of total nitrogen, but the sugar content decreased and insoluble and total solids increased.

GROWTH OF THE FRUIT AND THE ACCUMULATION OF VARIOUS CONSTITUENTS

The yield and the table quality of the fruit depend very largely on the amount of growth that has taken place at the time of harvest.

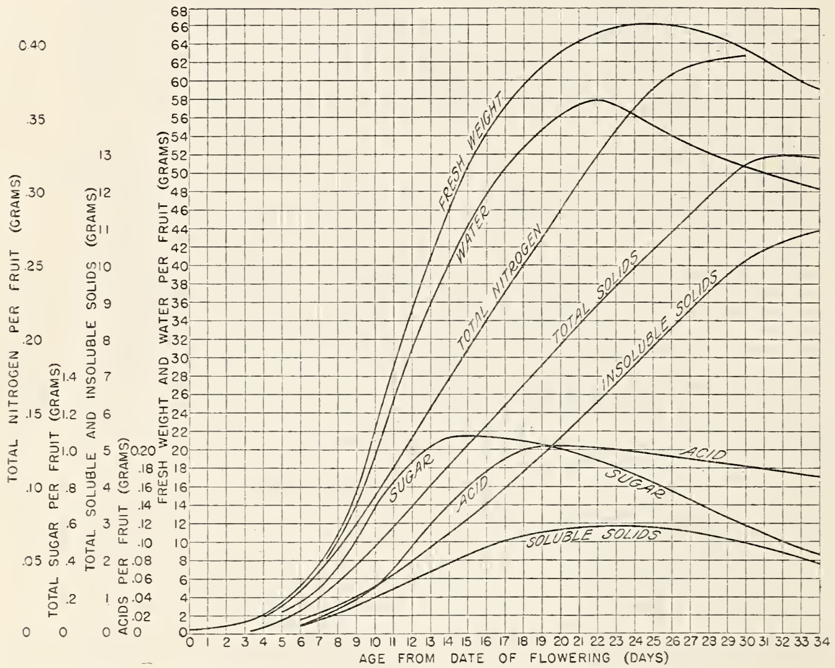

FIGURE 2.—The fresh weight per fruit of okra and net accumulation of some constituents with increase in age from date of bloom.

The fresh weight of the fruit increased slowly for the first 6 or 7 days, then rapidly and at nearly a constant rate to about the 17-day stage, then slowly to about the 22- or 23-day stage, after which there was a decrease to the 34-day stage. The growing period of the fruit may, therefore, be divided roughly into three periods according to the change in the fresh weight. The first may be termed the period of increasing rate, the second the constant-rate period, and the third the period of decreasing rate. The change in the fresh weight in the earlier stages of growth is chiefly the result of the net accumulation of water and secondarily of increase in solids; in the later stages it is due to accumulation of solids or dry matter consisting of several important constituents, accompanied by increase and later by decrease in water.

The rate at which the constituents accumulate and the relationship of the changes in the rates for each constituent to the rates of the others are shown in figure 2.

The curves showing accumulation of total solids, total nitrogen, and insoluble solids have rather long constant-rate periods. The sugars accumulate to about the 14-day stage and then decrease to the 34-day stage. The soluble solids increase to the 22-day stage and then

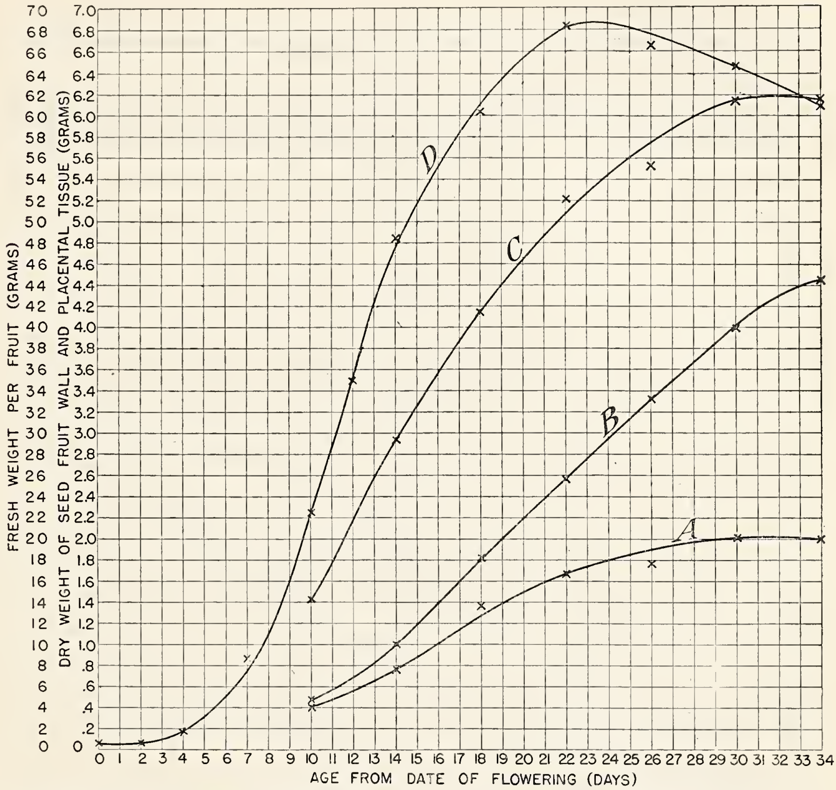

FIGURE 3.—Dry weight of seed and of the wall and placental tissues of the okra fruit when harvested at different ages from date of flowering. The fresh weight is also shown for comparison: *A*, Dry weight of placental tissue of okra fruit; *B*, dry weight of seed of fruit; *C*, dry weight of wall tissue of fruit; *D*, fresh weight of the entire fruit.

decrease whereas acidity increases to the 18-day stage after which there is little change.

Until the 8- or 10-day stage the seeds make up a very small part of the entire fruit. Beyond the 10-day stage the fresh weights of the seeds and the placental tissue were nearly equal, each being much less than the weight of the wall tissues.

The rates of accumulation of the total solids in the wall and placental tissue and in the seed are shown in figure 3. In the later stages of development the seeds accumulate dry matter much more rapidly

than do the tissues, whereas in the very early stages the wall tissue increases most rapidly in weight and the placental tissue most slowly.

The total sugars accumulate in all three parts of the fruit to about the 14-day stage, after which they decrease (table 2). From the 10-day stage onward nitrogen accumulated rapidly in the seeds to the 34-day stage, but the increase in nitrogen in the wall and placental regions was less rapid, ceasing and being replaced by decrease after the 30-day stage.

Effect of Temperature Upon the Elongation of the Fruit

The effect of the prevailing temperatures upon the rate of increase in length of the fruit for 5-degree intervals between 47.5° and 82.5° F. is shown in figure 4. The rate of elongation increases with increase

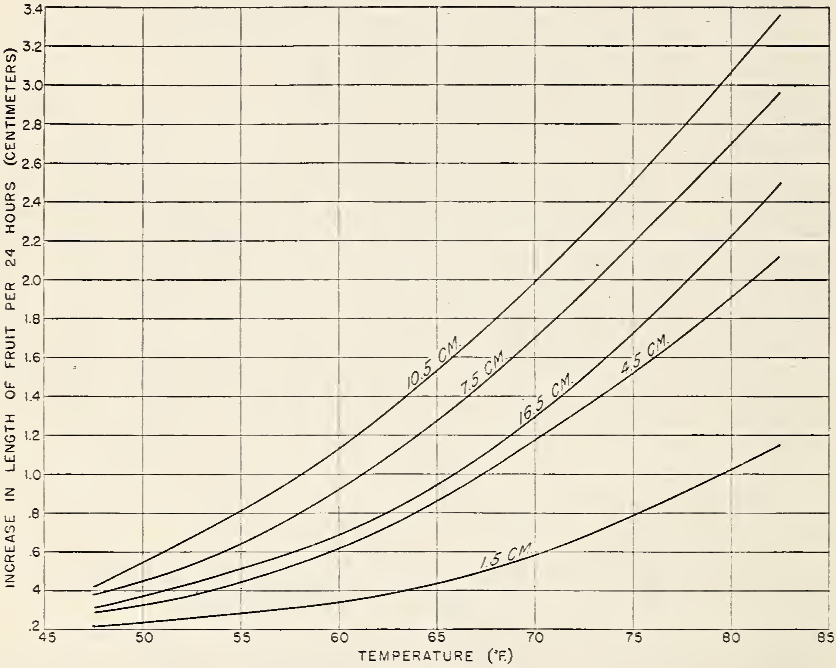

Figure 4.—Rate of increase in length of the growing okra fruit as affected by temperature. The various curves represent the rates for fruits of different lengths. The curves are based upon the average results of fruits that attained a final length of 15 to 20 cm., the average being 17.3 cm.

in temperature in a manner that is represented by lines of only moderate curvature. The most rapid rate of increase occurs at the higher temperatures. The rate somewhat more than doubled for each 18° F. (10° C.) rise in temperature at practically all stages of development and at every range of temperature. On this basis, harvesting of fruits would have to be made between two and three times as often at 78° as at 60° F.

The rate of growth also is different at different stages of development. The relationship between the rate of increase in length and the length

attained at any time is shown in figure 5. It is noted that the rate of increase in length becomes progressively more rapid from the flowering stage until the fruit is about 11 or 12 cm. in length and then becomes less and less rapid until the fruit has reached its final length (17.3 cm. in this material).

From the rates of growth, the periods of time required for the fruit to reach various lengths have been calculated and the results

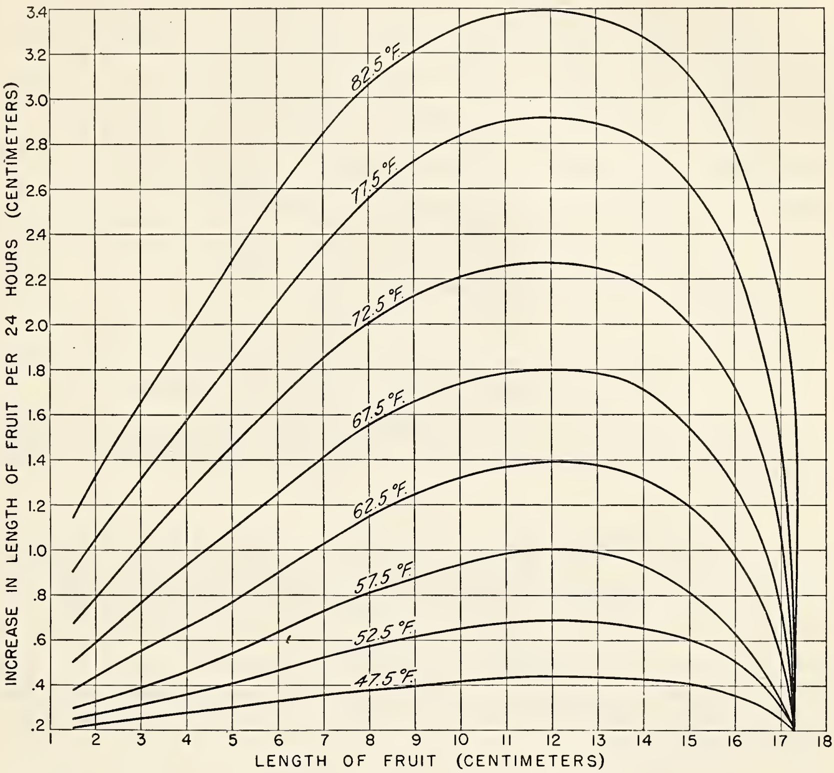

Figure 5.—Rate of increase in the length of the growing okra fruit as related to the length it has attained. The measurements were made in the field upon a group of pods that attained a final length of between 15 and 20 cm., the average being 17.3 cm. The different curves represent the rate of growth at different temperatures.

given in table 3. The general relationship of time and temperature to the amount of growth made is more clearly shown by the curves in figure 6. These curves take a somewhat different form from the curve of the fresh weight as shown in figure 2. This indicates that the fresh weight is not directly proportional to the length. This is due to the increase in diameter of the fruit. A large number of measurements of the diameters of the fruits were made, and it may be of interest to note that very often the diameter increased for a somewhat longer period than did the length of the fruit.

Effect of Day and Night on Growth

Measurements made at 8 to 9 a. m. and 4 to 6 p. m. showed that the rate of growth during the day averaged only slightly more than during the following night, in spite of the fact that the temperature was sometimes 10° to 12° higher during the day period. Thus at equal average temperatures the night period had a higher rate of

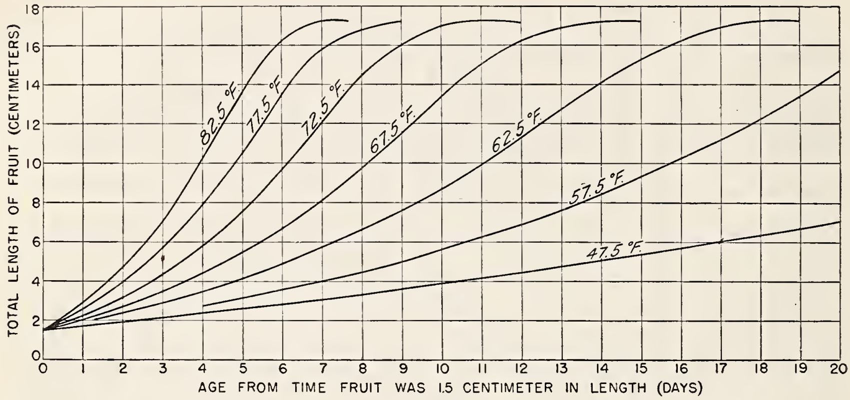

Figure 6.—Relationship between the age of the growing fruit and its length at various temperatures. The curves were plotted from estimated values obtained from the rates of growth of fruits of various lengths at various temperatures.

growth than the day period. Several factors may have contributed to this behavior. The greater relative humidity and the lessened transpiration during the night favored the accumulation of water in the fruit that in turn favored the extension of the fruit in length. It would have been of very great interest to have compared the rates of accumulation of the various chemical constituents during the day with those during the night. However, it was not possible to make the necessary number of analyses to determine the differences in the day and night rates.

Table 3.—*The estimated length of the fruit of the okra plant after various periods of growth at various temperatures*

[Calculated for fruits that attain a final length of 17.3 cm.]

Age (days)	Length of fruit when grown at temperatures (° F.) shown							
	47.5	52.5	57.5	62.5	67.5	72.5	77.5	82.5
	Cm.	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*
0	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
1	1.71	1.75	1.81	1.90	1.75	2.20	2.53	2.84
2	1.93	2.01	2.13	2.35	2.30	3.13	3.87	4.64
3	2.15	2.28	2.47	2.86	2.94	4.29	5.60	7.12
4	2.39	2.57	2.82	3.43	3.70	5.73	7.84	10.23
5	2.62	2.88	3.21	4.16	4.58	7.48	10.54	13.57
6	2.87	3.19	3.63	4.86	5.59	9.52	13.42	16.30
7	3.12	3.52	4.07	5.67	6.78	12.24	15.93	17.30
8	3.38	3.87	4.56	6.58	8.06	14.42	16.81	
9	3.64	4.22	5.08	7.62	9.66	16.01	17.30	
10	3.92	4.59	5.65	8.78	11.37	16.66		
11	4.20	4.99	6.27	10.05	13.15	17.05		
12	4.49	5.41	6.95	11.40	14.83	17.30		
13	4.78	5.85	7.70	12.78	16.41			
14	5.09	6.33	8.51	14.12	17.30			
15	5.40	6.82	9.37	15.34				
16	5.72	7.35	10.29	16.32				
17	6.05	7.90	11.26	16.97				
18	6.38	8.48	12.22	17.30				
19	6.72	9.08	13.22					
20	7.09	9.71	14.17					
21	7.46	10.36	15.03					
22	7.84	11.03	15.79					
23	8.22	11.71	16.37					
24	8.60	12.40	16.80					
25	9.00	13.09	17.13					
26	9.41	13.76	17.30					
27	9.82	14.41						
28	10.23	15.03						
29	10.68	16.61						
30	11.43	17.01						

Probably of greater importance than the effect of difference in humidity was the direct inhibiting influence of light.

COOKING TESTS

The observations upon the material cooked after harvesting at different ages are summarized in table 4. The color of the material did not vary greatly except at the 4- and 14-day stages, in which cases the material was darker than at the intermediate stages. The color was satisfactory at the 6- to 10-day stages. Beyond the 10-day stage the material was distinctly brown and became progressively darker with increasing age. Darkening was obviously due for the most part to the dark substances in the seed coats (*12*).

The flavor was always characterized by a mildness due to lack of acidity. The material was also decidedly lacking in sweetness. The flavor did not vary greatly at any stage of maturity. The material 4 to 6 days of age seemed to have somewhat more body or "substance" than the older material and probably for this reason seemed a little richer in flavor.

The most pronounced change accompanying increased age was the change in texture. The pectinlike, gummy, or mucilaginous substances that give okra its distinctive character were present at all stages tested. This character predominated to such an extent that the texture made no very important change until about the 10- or 12-day stage at which time a fibrous structure became noticeable and

quickly increased, rendering the material unsuitable for table use. At the 10- or 12-day stage the seeds had become large enough to be objectionable and contributed further to the undesirable texture.

TABLE 4.—*The effect of age upon the color, flavor, and texture of okra when cooked in 2-percent salt solution*

Age (days)	Average length	Color	Flavor	Texture
	Cm.			
4	2.8	Dark brownish green. Not best.	Mild, richest, pleasant. Very good.	Very tender but retains form. Good substance.
6	5.7	Brownish green. Good	Mild, pleasant. Very good.	Very tender. Tends to disintegrate slightly.
8	9.5	Light brownish green. Very good.	do	Very tender. Tends to disintegrate.
10	14.0	Light green. Very good	Pleasant. Good	Seeds slightly noticeable. Disintegrates.
12	16.5	Brownish green. Good	do	Fiber and seeds rather noticeable.
14	17.5	Dark brownish green. Poor	Somewhat under best	Fiber and seeds objectionable. Very poor.

There was a pronounced tendency for the material to shrink, collapse, and even to disintegrate in cooking or canning. The very young material held its form better than any other. There appears to be considerable air in the fruits, which is at least partly driven out during cooking. The specific gravity is low (table 5) and would indicate that 20 to 30 percent of the volume of the fruit is occupied by air. It is apparent that the specific gravity of the material decreases with age.

Tests were made upon the resistance of the outer coat of the fruit to puncture, using the pressure tester of Culpepper and Magoon (*6*). The results obtained during the period in which the chemical samples were taken are given in table 5. The instrument here used was unsatisfactory for this particular material and appears of little value either for estimating the age or the quality of the fruit. It would appear that an instrument designed to test the resistance of the fruit to cutting transversely would be more satisfactory, but no tests of this nature were made.

CANNING TESTS

The effect of age on the quality of the canned material was similar to that observed in the cooked material. The canned material was considerably darker and less green than the material after cooking. The difference in the amount of discoloration in young, medium, and old material was more pronounced than in the cooked material, the 14-day material appearing very unattractive. The flavor was fairly satisfactory, although considerably less pleasing than in the cooked material. The true flavor did not vary greatly in materials of different ages, but there was a slight preference on the part of the experimenters for the youngest material.

TABLE 5.—*The specific gravity and resistance to puncture of fruits of okra harvested at different ages*

Age of fruit (days)	Length	Specific gravity	Pressure test	Age of fruit (days)	Length	Specific gravity	Pressure test
	Cm.		*Grams*		*Cm.*		*Grams*
0	1.2		191	14	17.5	0.710	298
2	1.7		189	18	18.9	0.715	
4	2.3	0.852	227	22	19.0	0.708	
6	4.7	.841	258	26	19.8	0.687	
7	8.5	.742	257	30	19.0	0.659	
10	14.5	.765	264	34	19.5	0.665	
12	16.0	.702	293				

The tendency to disintegrate was more pronounced in the canned material than in the cooked. This tendency appeared most pronounced at the 8- and 10-day stages, and was probably due to the tender character and the rather higher moisture content at this time. The moisture content reached its highest point at the 14-day stage, but the material was then less tender and more fibrous. At stages younger than the 8-day stage the material was tender but had a lower moisture content and consequently appeared to have more substance. The material for canning was cut into short sections, and the presence of fiber was not objectionable quite so early in its development as in the cooked material. On the other hand, the seeds were more objectionable in the older samples of the canned material because they were much more apparent to the eye.

TIME OF HARVEST

From the standpoint of the quality of the material the most favorable time for harvest was judged to be when the fruit was 6 to 8 cm. (2.5 to 3 inches) long or approximately 6 days of age when grown at a mean temperature of 67.5° F. At this age the material has good color and flavor and excellent substance. It is tender and satisfactory in texture. Of course the actual age will depend upon the temperature, as shown in figure 6.

When both yield and eating quality are taken into consideration, the 8- or 9-day stage was judged to be the most desirable. The difference between the quality at the 6- and 8-day stage is not very great, but the yield increases very materially between 6 and 8 days, as this is the period of very rapid growth. The fruits are 9.5 to 13 cm. (4 to 5 inches) long at 8 to 9 days of age, so that the yield obtained by harvesting at this stage is approximately double that obtainable by harvesting at 6 days, and the eating quality has undergone very little change.

DISCUSSION

It is apparent that the material reaches a stage considered unpalatable a short time before growth in length ceases. This stage is reached long before the maximum amount of dry matter has accumulated in the fruit. The changes in the sugar and acidity are not of much significance in their effect upon the quality of the material. The character and amount of the total solids determine the "substance" and resistance of the material to disintegration. The pectin-

like substances and the mucilaginous materials are important, as well as the fiber (cellulose and lignin) content.

It is apparent from the rate of growth that the fruit is at the ideal stage for use for a very short period only. If the material is grown for market on a large scale it would be necessary to go over the plantings each day in the warmest part of the summer, in order to prevent some of the fruits becoming too old for use.

It should be remembered that these studies were confined to one variety for 1 year with the exception of the observations upon the effect of temperature on the crop. Some differences between varieties and also differences due to seasonal conditions are to be expected. From the practical standpoint, however, it is believed that these would not be of great importance, except as they affected the rate of development and the length of the growing period, and hence the length of the period of usefulness.

SUMMARY

Using field-grown okra the changes in certain constituents in the entire fruits, in the ovarial wall, the placental tissue, and in the seed have been determined at 1- to 4-day intervals from date of bloom to 34 days of age. Accompanying these analyses, measurements of the growth rates and the accumulation of the chemical constituents have been made. The eating quality has also been determined by the making of cooking and canning tests.

The total and the insoluble solids of the entire fruit decreased up to the 14-day stage of maturity and then increased to the 34-day stage, whereas the soluble solids made little change. The total sugars were low but increased somewhat to the 10-day stage after which there was a decline. The acidity and the total astringency made only slight changes that appear to be of no great importance as the fruits increase in age.

The fresh weight of the entire fruit increased slowly for the first few days after bloom, quite rapidly to the 14- or 18-day stage, then more slowly to the 22-day stage, after which there was a decrease. The insoluble solids, the total solids, and the total nitrogen also accumulated in somewhat the same way except that there was no decrease between the 22- and 34-day stages. The sugar accumulated to the 14-day stage, remained nearly constant to the 22-day stage, after which it decreased. The soluble solids increased to the 14-day stage and then decreased to the 34-day stage.

The effect of temperature upon rate of development of the fruit was studied by making measurements of the rate of increase in length at various mean temperatures from 47.5° to 82.5° F. The growth rate more than doubled for each increase of 18° F. (10° C.) in temperature.

The eating quality was judged to be rather high at the 4-day stage, increased somewhat to the 6-day stage, then slowly declined to the 10- or 12-day stage, after which time the material quickly became so fibrous as to be unsuited for table use. The factor that was most important in determining the eating quality of the cooked material was the texture. The texture is influenced or determined by the chemical and physical changes, chiefly the tenderness of the material and in the solids content, and by the nature of the changes in the dry

matter or solids. The material reached a degree of fibrousness that made it more or less undesirable for table use a short time before growth in length actually stopped.

LITERATURE CITED

(1) Association of Official Agricultural Chemists.
1930. official and tentative methods of analysis . . . compiled by the committee on editing methods of analysis. Ed. 3, 593 pp., illus.

(2) Beattie, W. R.
1905. okra: its culture and uses. U. S. Dept. Agr. Farmers' Bul. 232, 16 pp., illus.

(3) Campbell, Clyde H.
1937. campbell's book: canning, preserving and pickling. Rev. ed., 861 pp., illus. New York.

(4) Chatfeld, Charlotte, and Adams, Georgian.
1931. proximate composition of fresh vegetables. U. S. Dept. Agr. Cir. 146, 24 pp.

(5) Cruess, W. V.
1938. commercial fruit and vegetable products; a textbook for student, investigator, and manufacturer. Ed. 2, 798 pp., illus. New York and London.

(6) Culpepper, C. W., and Magoon, C. A.
1924. studies upon the relative merits of sweet corn varieties for canning purposes and the relation of maturity of corn to the quality of the canned product. Jour. Agr. Res. 28: 403–443, illus.

(7) Farmer, Fannie Merritt.
1935. the boston cooking-school cookbook. Rev. ed., 831 pp., illus. Boston.

(8) Hedrick, U. P., ed.
1919. sturtevant's notes on edible plants. N. Y. State Dept. Agr. Ann. Rpt. 27, v. 2, pt. 2, 686 pp.

(9) Jones, Henry Albert, and Rosa, Joseph Tooker.
1928. truck-crop plants. 538 pp., illus. New York.

(10) Malcolm, Ola Powell.
1930. successful canning and preserving; practical handbook for schools, clubs, and home use. Ed. 4, rev. and enl., 663 pp., illus.

(11) McElroy, K. P., and Bigelow, W. D.
1893. foods and food adulterants. canned vegetables. U. S. Dept. Agr., Div. Chem., Bul. 13, pt. 8, pp. 1015–1167

(12) Stevenson, A. E.
1924. discoloration in canned foods. Canning Age. 5: 951–952.

(13) Winton, Andrew L., and Winton, Kate Barber.
1937. the structure and composition of foods. v. 2. vegetables, legumes, fruits. 904 pp., illus. New York and London.

(14) Woodroof, J. G.
1927. okra. Ga. Agr., Expt. Sta., Bul. 145, pp. 162–185, illus.

ORGANIZATION OF THE UNITED STATES DEPARTMENT OF AGRICULTURE WHEN THIS PUBLICATION WAS LAST PRINTED

Secretary of Agriculture	Claude R. Wickard.
Under Secretary	Paul H. Appleby.
Assistant Secretary	Grover B. Hill.
Director of Information	Morse Salisbury.
Director of Extension Work	M. L. Wilson.
Director of Finance	W. A. Jump.
Director of Personnel	Roy F. Hendrickson.
Director of Research	James T. Jardine.
Director of Marketing	Milo R. Perkins.
Solicitor	Mastin G. White.
Land Use Coordinator	M. S. Eisenhower.
Office of Plant and Operations	Arthur B. Thatcher, *Chief.*
Office of C. C. C. Activities	Fred W. Morrell, *Chief.*
Office of Experiment Stations	James T. Jardine, *Chief.*
Office of Foreign Agricultural Relations	Leslie A. Wheeler, *Director.*
Agricultural Adjustment Administration	R. M. Evans, *Administrator.*
Bureau of Agricultural Chemistry and Engineering.	Henry G. Knight, *Chief.*
Bureau of Agricultural Economics	H. R. Tolley, *Chief.*
Agricultural Marketing Service	C. W. Kitchen, *Chief.*
Bureau of Animal Industry	John R. Mohler. *Chief.*
Commodity Credit Corporation	Carl B. Robbins, *President.*
Commodity Exchange Administration	Joseph M. Mehl, *Chief.*
Bureau of Dairy Industry	O. E. Reed, *Chief.*
Bureau of Entomology and Plant Quarantine	Lee A. Strong, *Chief.*
Farm Credit Administration	A. G. Black, *Governor.*
Farm Security Administration	C. B. Baldwin, *Administrator.*
Federal Crop Insurance Corporation	Leroy K. Smith, *Manager.*
Forest Service	Earle H. Clapp, *Acting Chief.*
Bureau of Home Economics	Louise Stanley, *Chief.*
Library	Ralph R. Shaw, *Librarian.*
Bureau of Plant Industry	E. C. Auchter, *Chief.*
Rural Electrification Administration	Harry Slattery, *Administrator.*
Soil Conservation Service	H. H. Bennett, *Chief.*
Surplus Marketing Administration	Milo R. Perkins, *Administrator.*

This circular is a contribution from

Bureau of Plant Industry	E. C. Auchter, *Chief.*
Division of Fruit and Vegetable Crops and Diseases.	H. P. Gould, *Principal Horticulturist, in Charge.*

U. S. GOVERNMENT PRINTING OFFICE: 1941